may be frozen in any convenient manner, such as placing it in a dry ice-alcohol bath for a sufficient time for the solution to freeze (generally about 1 minute for 100 µL of solution). The solution must be thawed at a temperature below the thermal denaturation temperature, which can conveniently be room temperature for most combinations of nanoparticle-oligonucleotide conjugates and nucleic acids. The hybridization is complete, and the detectable change may be observed, after thawing the solution.

The rate of hybridization can also be increased by warming the solution containing the nucleic acid to be detected and the nanoparticle-oligonucleotide conjugates to a temperature below the dissociation temperature (Tm) for the complex formed between the oligonucleotides on the nanoparticles and the target nucleic acid. Alternatively, rapid hybridization can be achieved by heating above the dissociation temperature (Tm) and allowing the solution to cool.

The rate of hybridization can also be increased by increasing the salt concentration (*e.g.*, from 0.1 M to 0.3 M NaCl).

The detectable change that occurs upon hybridization of the oligonucleotides on the nanoparticles to the nucleic acid may be a color change, the formation of aggregates of the nanoparticles, or the precipitation of the aggregated nanoparticles. The color changes can be observed with the naked eye or spectroscopically. The formation of aggregates of the nanoparticles can be observed by electron microscopy or by nephelometry. The precipitation of the aggregated nanoparticles can be observed with the naked eye or microscopically. Preferred are changes observable with the naked eye. Particularly preferred is a color change observable with the naked eye.

The observation of a color change with the naked eye can be made more readily against a background of a contrasting color. For instance, when gold nanoparticles are used, the observation of a color change is facilitated by spotting a sample of the hybridization solution on a solid white surface (such as silica or alumina TLC plates, filter paper, cellulose nitrate membranes, and nylon membranes, preferably a C-18 silica TLC plate) and allowing the spot to dry. Initially, the spot retains the color of the hybridization solution (which ranges

from pink/red, in the absence of hybridization, to purplish-red/purple, if there has been hybridization). On drying at room temperature or 80°C (temperature is not critical), a blue spot develops if the nanoparticle-oligonucleotide conjugates had been linked by hybridization with the target nucleic acid prior to spotting. In the absence of hybridization (*e.g.*, because no target nucleic acid is present), the spot is pink. The blue and the pink spots are stable and do not change on subsequent cooling or heating or over time. They provide a convenient permanent record of the test. No other steps (such as a separation of hybridized and unhybridized nanoparticle-oligonucleotide conjugates) are necessary to observe the color change.

An alternate method for easily visualizing the assay results is to spot a sample of nanoparticle probes hybridized to a target nucleic acid on a glass fiber filter (*e.g.*, Borosilicate Microfiber Filter, 0.7 micron pore size, grade FG75, for use with gold nanoparticles 13 nm in size), while drawing the liquid through the filter. Subsequent rinsing with water washes the excess, non-hybridized probes through the filter, leaving behind an observable spot comprising the aggregates generated by hybridization of the nanoparticle probes with the target nucleic acid (retained because these aggregates are larger than the pores of the filter). This technique may provide for greater sensitivity, since an excess of nanoparticle probes can be used. Unfortunately, the nanoparticle probes stick to many other solid surfaces that have been tried (silica slides, reverse-phase plates, and nylon, nitrocellulose, cellulose and other membranes), and these surfaces cannot be used.

An important aspect of the detection system illustrated in Figure 2 is that obtaining a detectable change depends on cooperative hybridization of two different oligonucleotides to a given target sequence in the nucleic acid. Mismatches in either of the two oligonucleotides will destabilize the interparticle connection. It is well known that a mismatch in base pairing has a much greater destabilizing effect on the binding of a short oligonucleotide probe than on the binding of a long oligonucleotide probe. The advantage of the system illustrated in Figure 2 is that it utilizes the base discrimination associated with a long target sequence and probe (eighteen base-pairs in the example illustrated in Figure 2),

yet has the sensitivity characteristic of a short oligonucleotide probe (nine base-pairs in the example illustrated in Figure 2).

The target sequence of the nucleic acid may be contiguous, as in Figure 2, or the two portions of the target sequence may be separated by a third portion which is not complementary to the oligonucleotides on the nanoparticles, as illustrated in Figure 3. In the latter case, one has the option of using a filler oligonucleotide which is free in solution and which has a sequence complementary to that of this third portion (see Figure 3). When the filler oligonucleotide hybridizes with the third portion of the nucleic acid, a double-stranded segment is created, thereby altering the average distance between the nanoparticles and, consequently, the color. The system illustrated in Figure 3 may increase the sensitivity of the detection method.

Some embodiments of the method of detecting nucleic acid utilize a substrate. By employing a substrate, the detectable change (the signal) can be amplified and the sensitivity of the assay increased.

Any substrate can be used which allows observation of the detectable change. Suitable substrates include transparent solid surfaces (*e.g.*, glass, quartz, plastics and other polymers), opaque solid surface (*e.g.*, white solid surfaces, such as TLC silica plates, filter paper, glass fiber filters, cellulose nitrate membranes, nylon membranes), and conducting solid surfaces (*e.g.*, indium-tin-oxide (ITO)). The substrate can be any shape or thickness, but generally will be flat and thin. Preferred are transparent substrates such as glass (*e.g.*, glass slides) or plastics (*e.g.*, wells of microtiter plates).

In one embodiment, oligonucleotides are attached to the substrate. The oligonucleotides can be attached to the substrates as described in, *e.g.*, Chrisey et al., *Nucleic Acids Res.*, **24**, 3031-3039 (1996); Chrisey et al., *Nucleic Acids Res.*, **24**, 3040-3047 (1996); Mucic et al., *Chem. Commun.*, **555** (1996); Zimmermann and Cox, *Nucleic Acids Res.*, **22**, 492 (1994); Bottomley et al., *J. Vac. Sci. Technol. A*, **10**, 591 (1992); and Hegner et al., *FEBS Lett.*, **336**, 452 (1993).